On Tidal Periodicity in the Earthquakes of Assam.—By R. D. OLDHAM, *Superintendent, Geological Survey of India.*

(Communicated by permission of the Director of the Geological Survey of India). [Received July 21st, Read August 6th, 1902.]

I.—INTRODUCTORY.

Ever since earthquakes were first studied there have been repeated and persistent attempts to trace the action of the sun, the moon, and the planets in producing them, or at the least in influencing their relative frequency. Mallet, from the discussion of his great earthquake catalogue [1], found that there was a marked periodicity, which caused earthquakes to have a maximum frequency towards the end of each century, with a minor, but nearly as great, maximum a little before the middle ; and, more recently, Dr. A. Cancani has remarked a similar peculiarity in the earthquakes of Italy.[2] Periods of this length, however, have no direct and obvious connection with the movements of the heavenly bodies, and more interest attaches to variations of shorter periods. Perrey, and following him Mallet,[3] believed that they had detected such variations, and that the frequency of earthquakes showed a relation to the distance of the sun and the moon from the earth, and to their relative positions in the heavens, at the syzygies and quadratures. As a result of this careful investigation it had been generally accepted that earthquakes were more frequent during winter than in summer and during the night than during the day.

In 1889 the subject was again attacked by M. F. deMontessus de Ballore,[4] who started by preparing a catalogue of 45,000 earthquakes. From this he proceeded to discuss the diurnal periodicity, and found that though each individual list and record showed a distinct periodicity, there was no agreement among them and that the larger the number of shocks taken the more uniform became the resulting distribution of earthquakes throughout the day and night. In a subsequent paper [5] he applied the same treatment to the seasonal periodicity with a similar result and came to the conclusion that there was no real variation in the frequency of earthquakes, which he regarded as a purely geological phenomenon, unaffected by either astronomical or meteorological influences.

About the same time Dr. Davison began his investigation of

[1] Rep. Brit. Ass., xxviiii, (1858).

[2] Boll. Soc. Sismol. Ital. vii, 205-209 (1901).

[3] Brit. Ass. Rep., xxviii, (1858).

[4] Archives des Sciences Physiques et Naturelles, 3. Ser., xxii, 409, (1889).

[5] Archives des Sciences Physiques et Naturelles, 3. Ser., xxv, 504, (1891).

earthquake frequency, and in a laborious paper,[1] on the annual and semi-annual periodicity of earthquakes, came to the conclusion that, treating each region separately, there was a distinct variation in frequency, which was in excess of that which might be expected if the occurrence of earthquakes was in no way connected with the seasons.

From this brief review it will be seen that the question, of whether earthquakes are at all affected by extra-terrestrial influences, is at present an open one, and for this reason I made every effort, after the great earthquake of 1897, to obtain the fullest possible record of the extremely numerous after-shocks, thinking that if there was any external cause at work it should be especially easy to trace at a time when, and in a region where, the earth's crust was evidently in an extremely unstable condition. The discussion of these records is not complete but in the case of one of them it has been completed, so far as one particular phase of the frequency is concerned, and the results obtained appear to be of sufficient interest to justify some notice of them.

In July of 1897, Mr. T. D. LaTouche, who was then in Shillong reporting on the results of the earthquake, constructed a seismograph on the duplex pendulum system, which was set up by the Executive Engineer, and from which continuous records have been taken ever since. The instrument, like all seismographs, is far from a perfect one, it does not record many shocks which can be distinctly felt, and it does not record the time, yet the records are of great value. In the first place we know that every shock recorded attained a certain standard of range of motion of the wave particle and of violence, if such a word may be applied to what in many cases are merely slight shocks, and that all the shocks exceeding this standard are recorded. The absence of automatic time record is more serious, but as the time of the shock was, in every case, recorded by the observer we may take it that there is no very serious error or omission in this respect. Every shock recorded represents one at approximately the time given, and the only cause likely to affect the periodicity is a possible error in the case of the night shocks: it is possible that the instrument may at times have registered a shock while the observer was asleep, and the record afterwards referred to one, felt when he was awake, which did not affect the instrument. The uncertainty due to this cause is, however, slight, as the gentlest shock registered by the instrument is sufficiently strong to usually awake a sleeper.

From this instrument we have received records from August 1897, but those discussed as yet only extend to the end of 1901; so far they have only been examined with a view to the hourly variation in

[1] Phil. Trans. clxxxiv, A, 1107 (1893).

frequency, and instead of contenting myself with a mere record of the relative frequency of the earthquakes, as has usually been done in the past, I have made an attempt to see whether there is any trace of extra-terrestrial influence in this frequency.

As pointed out by me in a short note published in 1901[1] any effect which the attraction of the sun and the moon may have, will be most effectively, if not solely, exerted by the Tide-producing forces they set up, and that, to trace the effect of these, it is not sufficient to merely tabulate earthquakes by the hours in which they occur. The time at which the tide-producing forces reach their maximum depends on the declination of the sun and the moon, that is to say it is subject to seasonal variations, and to determine whether these forces have any influence it is necessary to classify the records, according to the position of the sun or moon with reference to the equator, and then examine the frequency to see whether there is any variation which can be correlated with the tidal forces.

II.—Statement of the Problem.

There is neither space nor occasion to recapitulate what is known of the theory of the tides, but a brief account of the form of the tide-producing influence of the attraction of the sun and the moon is desirable, that the nature of the effect to be looked for may be clearly understood, and the review will be simplified by the fact that we need not consider the theory of the tides themselves, but merely of the stresses to which they owe their origin. Omitting all reference to the why, it will be sufficient to point out that the effect of the attraction of a satellite—and in this connection the sun is regarded as a satellite equally with the moon—is to produce a stress equivalent to an upward force at the spot which is at any moment directly under the satellite, and at the antipodes of that spot. Along the great circle half way between these two spots, separated from each by 90° of arc, there is a force acting downwards towards the centre of the earth, and equal in amount to one half of the upward force. At spots between these two points and the great circle just referred to, the stresses produced are equivalent to forces acting in directions away from the vertical, and along a circle which is distant about 54° 44′ 14″ from the spots where the satellite is in the zenith or nadir the force acts horizontally.

Now if we suppose the force exerted at any point to be resolved into two separate forces, one acting vertically and the other horizontally, then the vertical force attains its upward maximum where the satellite is in the zenith or nadir, and its downward maximum along the great circle intersecting the line joining these two points and lying at right

[1] Geol. Mag. 4. Decade, viii, 449, (1901).

angles to it. The horizontal force attains its maximum along two circles distant about 54° 44′ from the zenith and nadir respectively, the direction being towards the satellite in the former case and away from it in the latter. If then the tidal stresses have any influence in determining the time of origin of earthquakes we should look for the effect in connection with these circles.

Both sun and moon, as is well known, vary their position in the heavens, travelling alternately north and south of the equator, the sun moving to about 23°, and the moon to about 26°, from it. From this it follows that neither can ever be in the zenith of any spot distant more than 26° from the earth's equator, that is in more than 26° of latitude either north or south, and no spot situated outside those limits can ever experience the maximum upward force. Within those limits, at either one or two periods in each year, when the declination of the sun and the latitude of any given place are the same in amount and sign, the maximum upward force, due to the sun, will be experienced at midday and midnight; and similarly in each lunar month there will be either one or two periods at which the maximum upward force will be experienced, when the moon is either overhead, mid-moon-day, or underfoot, mid-moon-night. Outside the limits of the two 26° parallels, and within them at all times when the declination of the sun or moon is different in amount or sign from the latitude, the maximum upward force will not be experienced, but, as the earth revolves on its axis, the circles of maximum horizontal and downward force sweep over its surface, and pass any given place at an interval, before and after the meridian passage of the satellite, which depends on the declination of the satellite at the time and the latitude of the place.

From these considerations it will be seen that, before discussing the frequency of earthquakes with reference to the tidal stresses, it is necessary to group them according to their place of origin, and then see whether, for any one district, there is a connection between the relative frequency of earthquakes and the times of passage, over the epicentre, of the circles of maximum tidal force.

One method of discovering whether there is any such connection would be to calculate for each earthquake the exact time which separated the time of its origin from that of the passage of each of the circles of maximum tidal force, and then to classify the records according to these intervals, and see whether there was any preponderance of earthquakes at or about these times. The process would be a laborious one, and, in view of the want of exact accuracy in the times, did not seem worth going through, as a result within the limits of accuracy of the records can be obtained in a simpler manner.

We may assume that the epicentres of the earthquakes now under consideration all lie in 26° N. Lat., without introducing any material error, and, calculating for that latitude the time intervals, which elapse between the meridian passage of the satellite and the passage of the tidal circles, we obtain, for extreme and mean values of declination the intervals given in the tabular statement below,[1] where 0 h represents the lower, and 12 h. the upper, meridian passage, or midnight and midday in the case of the sun.

I.—*Table showing the times of passage of circles of maximum horizontal and vertical Tide-producing force; calculated for Lat. 26° N.*

Decl.	Hor. force, Direct.	Vert. force, Downward.	Hor. force, Indirect.
	12 h. ±	0 h. ±	0 h. ±
	h. m.	h. m.	h. m.
26° N.	4-15	4-38	——
9° N.	3-31	5-34	2-14
0°	2-59	6-0	2-59
9° S.	2-14	6-26	3-31
26° S.	——	7-22	4-15

From this table it is obvious that, if the total number of shocks is divided into three groups, according to the position of the sun, the first comprising those which occurred when the sun was more than 9° N., the second when its declination did not exceed 9° N. or S. and the third when the declination was more than 9° S., then in the first group the effect of the horizontal force must be looked for between $3\frac{1}{2}$ and 4 hours before and after midday, and within two hours on each side of midnight; in the second group the effect is to be looked for between 3 and $3\frac{1}{2}$ hours on either side of midnight and midday; while in the third the condition will be the same as in the first, with the substitution of midnight and midday. Moreover, as the effect may be due rather to the rapidity of changes in the amount, than to the actual amount, of the force exerted, the horizontal force may have but small influence when the passage of the circles takes place at less than two hours on either side of the meridian passage, that is to say, when the intersection of the circles is oblique, and the rate and range of change in the amount of force is less than when the passage takes place at a greater time-interval than 2 hours from the meridian passage. This, combined with the much greater length of time during

[1] The intervals are not exactly the same on either side of the meridian passage on account of the motion of the sun and moon in the heavens, but the inequality is not sufficient to be of importance in this connection.

which the interval exceeds three hours, shows that in a general list of all the shocks the effect must be looked for between 3 and 4 hours on either side of midday and midnight. Further, as it is a common phenomenon in nature that the maximum of effect lags behind the maximum of cause, it may be that the effect will not be found between 3 and 4 hours on either side of the meridian passages, but at some time after that epoch. Another effect which may be looked for, which follows from the consideration of the greater efficiency of the force when its rate of variation is greater, is that we may expect the number of shocks recorded during the day to be proportionately greater when the sun is more than 9° N., that is during the summer, and the night shocks to be proportionately more numerous during the winter, when the sun is more than 9° South of the equator.

There is another supposition which must also be tested, that the effect, if any, of the tidal forces is not to be looked for in connection with the times when they attain their maximum, but with the times at which the rate of change, of amount and direction of the forces, is at its maximum. For any particular place the rate of change always reaches its maximum at 3 hours before and after the meridian passage, but along a great circle, passing through the place of observation and the place where the satellite is in the zenith, the maximum rate of change is at 45° from the latter, and it will be useful to see what is the time interval for different declinations at which a circle 45° distant from this spot passes the place of observation. The result is given in the following table.

II.—*Times of passage of circles of maximum rate of change of the Tide-producing forces calculated for Lat.* 26° *N.*

Decl.	Direct.	Indirect.
	12h ±	0h ±
	h. m.	h. m.
26°N.	3-22	——
9°N.	2-56	1-56
0°	2-33	2-33
9°S.	1-56	2-56
26°S.	——	3-22

It must be distinctly understood that the times given in this table are not those at which the rate of change is actually greatest, but those at which the rate is greatest, as measured along a different circle to the east and west one, along which the place of observation travels. In the solitary case where this place and the satellite are both on the equator the two agree, and in no other; but the table is useful, for the closer the value in the table approximates to 3 hours the greater is that rate of change, and the closer it lies to 0 h. or 12 h. the less is the rate of variation of the tide-producing forces.

The passage of the circles of maximum vertical force is not subject to the same changes as that of the other circles, and never varies more than 1 h. 22 m. from six o'clock; the effect of this force must therefore be looked for about that time in the morning and evening or somewhat later.

Finally, it is necessary to notice one objection, which might be raised to the preceding passages, that the effect is not necessarily to be looked for at any fixed time before or after the meridian passage of the satellite, but that, for each place, there will be something equivalent to what is known as the "establishment" of a port in the case of marine tides. The objection, however, is not valid, for in this case we have not to do with free travelling waves, like that of the tides, which take a greater or less time to travel from the place where they originate to the place where they are felt, but with the direct effect of the stresses which produce the waves. These depend solely on the latitude of the place and the declination of the satellite, and for them there is nothing in any way analagous to the " establishment " to be considered.

III. Discussion of the Data.

After this preliminary exposition of what is to be looked for, we may pass on to a consideration of the results obtained. In the record discussed there are contained 1274 distinct shocks, and, on counting these, it was found that, in each hour of the twenty-four, the number of shocks recorded was as given in the tabular statement No. III, where all shocks recorded from 0 h. to 0 h. 59 m. are placed under 0, those between 1 h. and 1 h. 59 m. under 1 and so on.

The most casual inspection of this table shows that the shocks are not at all uniformly distributed during the twenty-four hours, and that there is a great preponderance during the hours preceding midnight, with a lesser increase towards 6 A.M. It may also be noted that the night shocks seem more numerous when the sun is more that 9° S and the day shocks when it is more than 9° N, but no proper comparison is possible on account of the difference in the total number of shocks in each line. For comparison they must be brought all to the same ratio, and this may be done, either by calculating the percentage of the total number of shocks recorded in each hour, or more simply by dividing each figure by the mean value for the line; this gives a result showing the proportion of the number of shocks recorded in each hour to the average number for one hour. In this way we get the result shown in the next tabular statement.

III.—*Hourly distribution of Shocks.*

Sun's Declination \ Hours	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	TOTAL.
>9°N ...	11	15	16	12	13	24	24	8	22	12	22	21	16	13	22	12	27	16	14	17	21	30	28	20	436
9°N-9°S ...	5	8	14	14	26	14	16	16	9	15	13	14	11	18	9	22	22	11	12	13	19	17	21	19	358
>9°S ...	17	21	29	29	22	19	30	16	10	15	8	19	16	12	17	13	22	19	22	20	20	24	41	19	480
TOTAL ...	33	44	59	55	61	57	70	40	41	42	43	54	43	43	48	47	71	46	48	50	60	71	90	58	1274

IV.—*Proportionate distribution of Shocks by hours.*

Sun's Declination \ Hours	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
> 9°N ...	·61	·83	·88	·66	·71	1·32	1·32	·44	1·21	·66	1·21	1·16	·88	·72	1·21	·66	1·49	·88	·77	·93	1·16	1·65	1·54	1·10
9°N-9S ...	·33	·54	·94	·94	1·74	·94	1·07	1·07	·60	1·01	·87	·94	·74	1·21	·60	1·47	1·47	·74	·81	·87	1·27	1·14	1·41	1·27
>9°S ...	·85	1·05	1·45	1·45	1·10	·95	1·50	·80	·50	·75	·40	·95	·80	·60	·85	·65	1·10	·95	1·10	1·00	1·00	1·20	2·05	·95
All shocks ...	·60	·80	1·09	1·02	1·19	1·07	1·30	·77	·77	·80	·83	1·02	·80	·84	·89	·93	1·35	·86	·89	·94	1·14	1·32	1·67	11·1

Shillong Seismograph 1897-1901. Hourly curve of frequency smoothed by means of 3 hours.

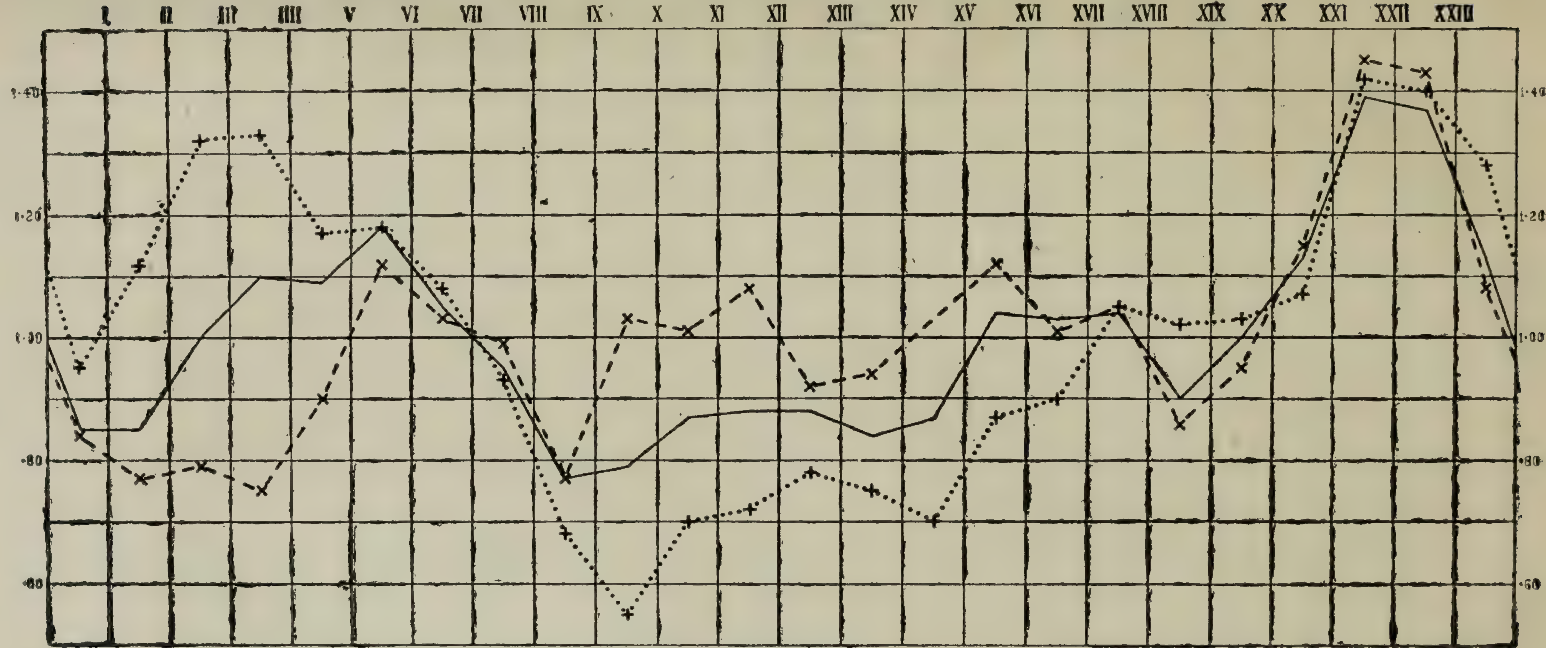

Fig. 1. Curves of diurnal distribution of earthquakes. The continuous line is the general curve obtained from all shocks. The broken line represents the distribution of shocks occurring when the sun's declination was more than 9°N. The dotted line is the curve for shocks occurring when the declination as more than 9°S.

Here we again see that the day shocks are proportionately more numerous when the sun has declination of more than 9°N. than when the sun is more than 9°S. of the equator, and that in the latter case the night shocks are proportionately more numerous than in the former. It is also evident, from the irregularity of distribution from hour to hour, that the number of shocks is not enough to give a near approach to the true curve, when plotted directly, and a process of smoothing has to be adopted. This has been done by adding together the number of shocks recorded during each group of three successive hours and, by regarding them as grouped round the centre of the middle hour, obtaining a fresh series of hourly means, from which a great deal of the irregularity of the curve has disappeared. The result is represented graphically in Fig. 1, so far as the shocks which occurred when the sun was more than 9° north and south of the equator respectively.

From this curve it will be seen that as regards the shocks occurring about two hours before midnight there is little difference, but that for the rest of the twenty-four hours the curve for south declination is steadily above that for north declination throughout the twelve hours of the night, and below it for the day. Moreover there is a distinct maximum in the earthquakes recorded round three hours after and two hours before midnight, while the earthquakes recorded near midnight are much more frequent than when the sun was more than 9° north of the equator. Turning to the shocks recorded when the sun was north of the equator, not only are they proportionately more numerous, than when it was south but there is again a distinct pair of maxima, shortly before and three hours after midday. Among the shocks recorded when the sun was within 9° of the equator we have maxima distinctly marked at about 5 hours after midnight and midday, another at about 2 hours before midnight and a less marked one at about 2 hours before midday.

There is consequently an approach to what might be expected if the tide-producing forces caused by the attraction of the sun had their effect in determining the time of origin of earthquakes, but it is also evident that, if these forces have any effect, it is so small and so complicated by other causes, giving rise to a greater variation in frequency than they do, that it is necessary to adopt some method of discussion, which will more or less completely eliminate the effects of variation, other than those due to the tide-producing forces.

The most obvious of these would be the conversion of the solar into lunar times. The moon moves through the heavens at a rate which brings it on the average about 50 minutes in advance of the sun for each day. If, then, we consider the interval between the two successive similar meridian passages of the moon as representing 24 lunar hours, and convert the recorded times into lunar times, it is obvious that, in a long series of observations, any irregularity of frequency, at any particular hour of solar time, will get spread over the whole of the lunar day, and in its place will be introduced any fresh irregularity due to the position of the moon. Now as the moon has twice the efficiency of the sun, as a tide producer, any irregularities due to the tide producing forces should be double as great as in the case of the sun.

Unfortunately the test cannot be applied in this case as, on trial, it was found that the series of observations was not sufficiently long to eliminate the effect of the diurnal irregularities.

This method of elimination failing, we must fall back on the recorded times, to see whether there is no other method of eliminating the non-tidal diurnal variation, and a method appears which depends on the fact that, taking the year as a whole, the tidal effect is on the average the same all through, since the times of passage of the tidal circles during the six hours on either side of midnight are the same for a south declination as the times on either side of midday in the case of the same amount of north declination.

If, then, we take the recorded frequency of shocks for each hour, write them down in two lines, placing those for the hour after midday under those for the hour after midnight and so on, and then add the two lines, we obtain a series of numbers representing the semi-diurnal curve of frequency. In this curve any diurnal periodicity, which is of a harmonic nature, is completely eliminated, and any non-harmonic periodicity largely reduced in amount. On the other hand any semi-diurnal periodicity which is harmonic in character, or which, if not harmonic, has its irregularities similarly distributed with regard to midnight and midday, will be exaggerated; that is to say the effect we are looking for will be increased, while that which we wish to eliminate will be reduced, in amount.

In the next tabular statement the process is illustrated as regards the total number of shocks, and four more lines given, showing the results obtained in the case of certain combinations of shocks, which will be referred to further on.

V.—*Semidiurnal distribution of Shocks.*

Hours.	0 12	1 13	2 14	3 15	4 16	5 17	6 18	7 19	8 20	9 21	10 22	11 23
All shocks 0 h. to 11 h. Do. 12 h. to 23 h. Sum	33 43 76	44 43 87	59 48 107	55 47 102	61 71 132	57 46 103	70 48 118	40 50 90	41 60 101	42 71 113	43 90 133	54 58 112
Sum ÷ Mean	·72	·81	1·01	·96	1·26	·97	1·11	·85	·95	1·06	1·25	1·05
Day shocks > 9° N. Night shocks > 9° S.	·80	·82	1·23	·99	1·18	·84	1·11	·67	1·01	·87	1·52	96·
All shocks 9° N. to 9° S.	·53	·87	·77	1·20	1·61	·84	·94	·97	·94	1·08	1·14	1·11
Day shocks > 9° N. All shocks 9° N. 9° S. Night shocks > 9° S.	·69	·84	1·04	1·08	1·36	·84	1·04	·80	·98	·95	1·36	1·02
Night shocks > 9° N. Day shocks > 9° S.	·77	·77	·94	·71	1·00	1·23	1·26	·94	·94	1·29	1·03	1·12

Here we see two very marked maxima, in the distribution of the shocks, one during the fifth hour after, the other during the second hour before, the meridian passage, and these maxima may be taken as grouped around $4\frac{1}{2}$ hours and $10\frac{1}{2}$ hours of the morning and afternoon. That is to say they both follow by $1\frac{1}{2}$ hours the epoch corresponding to three hours before and after the meridian passage, a time which corresponds more closely to the passage of the maximum rate of change of tidal force, than to that of the circle of maximum horizontal stress.

If we turn to the next line in the table, representing the distribution when the tide producing forces may be expected to be most effective, we find the same features, except that the maximum following the meridian passage is less marked than that which precedes it, and that though the latter is proportionately greater than in the case of the whole number of shocks the former is less.

The next line shows the distribution when the sun is within 9° of the Equator, when on the average the conditions—so far as the tide generating forces are concerned—are the same during the day as the night. Here we find the two maxima again, but it is that following the meridian passage which is most conspicuous, the other being small and ill defined.

The fact is that in both these cases the total number of shocks considered is too small to get an approach to a true average, and, in this small number of shocks, accidental variations of distribution may produce an irregularity of the curve which exceeds its normal variation.

To some extent this difficulty may be overcome. If we refer to the tables I and II, we will see that when the sun is within 9° of the equator, there is not a very great variation in the times of passage of the tidal circles as compared with the times of passage during the day when the sun is north, and during the night when it is south, of the equator. On the other hand the night when the sun is north, and the day when the sun is south, of the equator, show a much greater range of time in the passage of the circles and not only is the range of time greater and the effect consequently less conspicuous, but during part of the time the maximum of horizontal force is not felt at all, and during the rest of the time the passage is so oblique that the rate of change is slow and the tidal forces probably less effective.

Excluding these shocks we may add together the two groups of shocks already considered and so obtain a larger one, in which the tidal effect is tolerably uniform. The rèsult is given in the table, and shown graphically in Fig. 2. Here it will be seen that the two maxima preceding and following the meridian passage are both distinct, and exceed those obtained from the total number of shocks.

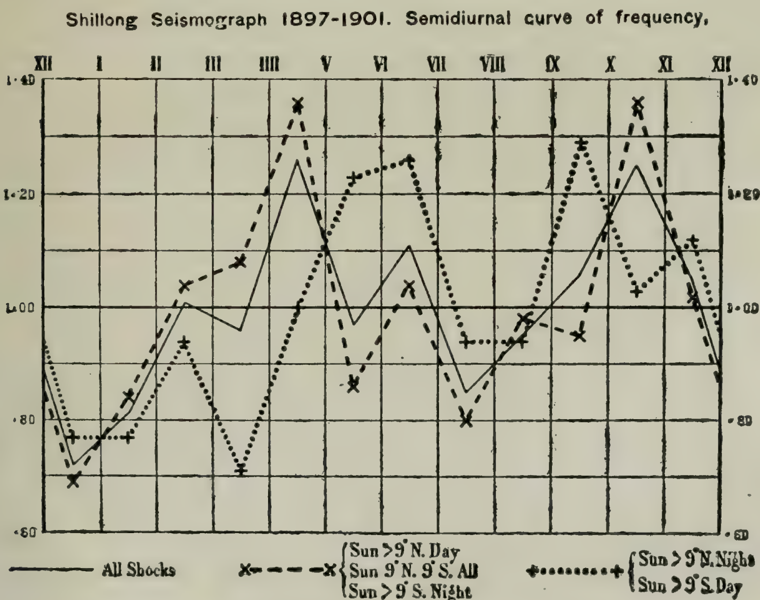

Fig. 2. Semidiurnal curves of frequency.

We have consequently the effect which was to be looked for if the frequency of earthquakes is influenced, either by the amount of the horizontal tide generating force, or by the rate of change of the tide generating forces, and the fact that this effect becomes more marked the larger the number of shocks—suitably distributed as regards time of occurrence—which are taken into consideration, lends support to the supposition that the apparent relation between cause and effect is a real one.

Passing on to the last line, representing the night shocks when the declination is north and the day shocks when it is south, that is to say a time when the rate of variation of the tidal stresses is at its lowest and less effect to be looked for, we find that the marked maxima have disappeared, and that there is an almost equally distinct increase in frequency about six o'clock, that is at a time corresponding to the passage of the circles of maximum vertical force. This has the appearance of indicating that the purely vertical stresses have less influence than those which have a large element of horizontal stress, and that the effect of the former only becomes apparent when that of the latter becomes small. Too much stress must not, however, be attached to this conjecture, as the number of shocks dealt with is smaller than in any of the other combinations, and the possibility of fortuitous irregularities in the curve more probable in a corresponding degree, and besides this the effect here only lags half an hour behind the presumed cause, while in the case of the $4\frac{1}{2}$ and $10\frac{1}{2}$ hour maxima it lags $1\frac{1}{2}$ hours behind the presumed cause.

It appears then that the tidal stresses have a distinct effect in determining the time of origin of earthquakes, though their influence is small in proportion to other causes, but at the same time it is necessary to enter a caution that, though the facts in this case seem to support the conclusion, they are far from proving it. For proof a more extended series of observations are required, not only from Assam, but from other stations also, and even in the record discussed in this paper there is reason to doubt the correctness of the conclusion, inasmuch as the effect found appears to be out of proportion to the cause invoked.

When we consider that the maximum upward tidal force exerted by the moon is only 1/8, 450,000 of gravity, that this corresponds very closely to the difference in downward strain which would be produced by the removal or replacement of half a grain on a one-ton weight, that the maximum horizontal tide generating force is only three quarters of this, and finally that the tide generating forces set up by the sun are a little less than half of those set up by the moon, it is surprising that they should have any effect at all. On the other hand when we consider that these forces are sufficient to give rise to the tides, and that the difference between the spring tides and the neaps is due to the forces whose effect has been searched for in this paper, it is quite conceivable that they should not be without effect in determining the moment at which a gradually increasing strain becomes too great for the resistance, and the fracture is produced which gives rise to an earthquake.

IV.—Conclusions.

From what has gone before we may draw the following conclusions.

1. That there was a very large variation in the diurnal distribution of earthquakes in Assam during the years 1897-1901, shocks being most frequent between 10 and 11 p.m., and again between 6 and 7 a.m. This greater frequency is a real one and not merely due to a larger number of shocks happening to be recorded at those times.

No satisfactory cause can be assigned for this irregularity of distribution, which must for the present be accepted as a fact true for a limited period and area.

2. Superimposed on this large and unexplained variation in frequency, there is a smaller variation which has the appearance of being due to the tidal stresses set up by the attraction of the sun.

3. If this smaller variation is really due to tidal stress, then the horizontal stress is much more efficient than the vertical stress, and the effect is less due to the amount of the stress than to the rate and range of its variation.

4. That these conclusions must be taken as purely provisional and require verification from a more extended series of observations. For their verification we require an instrumental record from some station within or near the tropics, where earthquakes are fairly frequent, and extending over 19 or 20 years.